The Use of Tethered Balloons to Measure the Evaporation Duct

LEUT Robyn Phillips, RAN

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Introduction

An evaporation duct is created by a rapid decrease of relative humidity immediately adjacent to the air-sea interface. This occurs because the air in contact with the ocean's surface is saturated with water vapour. A few metres above the surface the air is not usually saturated, so there is a gradient associated with the decrease of water vapour pressure between the surface and some height well above the surface. This affects the modified index of refraction, M and creates an evaporation duct. These ducts exist all over the oceans with heights varying from one to two metres during winter nights, to as much as 40 metres during summer days.

Bulk methods using surface parameters are an accepted method to calculate the evaporation duct height. It is difficult to confirm the accuracy of these methods, as the lowest part of the surface layer cannot be measured using typical rawinsonde flights or microwave refractometers. In an attempt to assess the accuracy of the bulk methods, experiments have occurred using a rawinsonde attached to a kite to measure the lowest part of the surface layer. The results suggested that the data collected by the kite showed higher evaporation duct heights than the bulk methods were predicting. Low-level kite flying requires a certain skill level and a certain amount of wind. In times when these conditions are unavailable, a tethered balloon appears to provide an alternative option. The purpose of this study is to assess the suitability of using a tethered balloon to carry a rawinsonde to sample the surface layer for evaporation duct height measurements.

Measurements

For this project, two flights were conducted using a rawinsonde attached to a kite, and four flights were conducted using a tethered balloon instead of the kite (see figure 1). The kite/balloon was used to collect air temperature, relative humidity, pressure and dew point temperature. This was done six times, 2 Aug 01 at 2312UTC, 4 Aug 01 at 1928UTC, 5 Aug 01 at 1549UTC, 5 Aug 01 at 1746UTC, 8 Aug 01 at 2126UTC and 9 Aug 01 at 0118UTC. The data was sampled every two seconds for the duration of each flight as the kite was raised and lowered. During each flight, manual observations were recorded noting at what times the rawinsonde was lowered to sea level and to what approximate height.

Figure 1: The tethered balloon in flight carrying a rawinsonde.

R/V Point Sur’s Serial ASCII Interface Loop (SAIL) system was used to measure the atmospheric variables required to obtain profiles of M using bulk methods. The system recorded air temperature, wind speed (starboard true wind speed), relative humidity, pressure and sea surface temperature. The sea surface temperature was measured using the boom probe. The data was received after being averaged over 52 to 58 second intervals. All of the instruments (excluding the boom probe) were mounted 17 metres from the sea surface.

Problems and Assumptions

Before describing the results obtained from the flights, it is important to discuss the limitations and assumptions that affect the data. First, there is a certain level of skill in manoeuvring a kite when it is within metres from the ocean’s surface. The kite would often suddenly dive down causing the sonde to go a little too close to the water, and sometimes getting wet. Although the data readout was always checked after such an occurrence, the sensors are likely to be affected by such an event.

The tethered balloon is easier to control at similar low heights, assuming the winds are not too strong. The balloon is difficult to get low enough for the rawinsonde to measure just above the surface without being too close to the ship and thus contaminating the data. Often, the scientist would hold the string attached to the rawinsonde dangle the rawinsonde over the side of the ship to try and measure very low heights.

Due to the aerodynamic characteristics of a kite, there are certain wind requirements in order for the kite to fly successfully. Enough wind is required for the kite to become and stay airborne, but too much wind may damage the kite’s frame. During the project, the kite was only flown between 10 and 25kts of wind. The balloon is not suited for stronger winds as the shape of the balloon flattens with increasing wind strength. It is ideal to use when the winds are not strong enough to support the kite.

The height of the rawinsonde is calculated from pressure. Inaccuracies to the height may be due to the surface pressure not being constant during each flight, although observations indicate that generally, there was only ±0.5hPa fluctuation. The rawinsondes were also of unknown calibration, and during the initialisation process of the Vaisala equipment, the surface pressure used was the rawinsonde readout, not the SAIL surface pressure. If the rawinsonde was on the upper deck during the initialisation process, several metres above the ocean's surface, this could cause the negative heights that were observed in the data. This was often the case when using the balloon, as the rawinsonde would be initialised next to the balloon at the same time the balloon was being inflated.

The initialisation period of the rawinsonde was also the time the kite or the balloon was prepared. For most of the flights, there was a period of several minutes where the rawinsonde was sitting on deck or in a scientist's hand while the balloon and kite were getting ready to launch. For the kite, there were often several attempts to get the kite airborne before releasing the rawinsonde.

There is thought to be a small time lag of approximately two to three seconds for the sensors to adjust to their environment. A close look at the data in table 1 shows that during some ascents the rawinsonde travelled over 20m in two seconds. A time lag adds to the problems of poor spatial resolution. Very few measurements were recorded over a crucial part of the atmosphere for the purpose of measuring the evaporation duct, and the measurements at, for example, 30m could still be the values observed at 5m.

Time (min s)	**Ascent Rate (m/s)**	**Height (m)**	**Pressure (hPa)**	**Temperature (°C)**	**Relative Humidity (%)**
12 52	-0.1	7	1016.2	13.4	91
12 54	-0.1	5	1016.5	13.4	91

12 56	-0.1	7	1016.2	13.4	91
12 58	-0.1	5	1016.5	13.4	91
13 0	0.8	28	1014.0	13.3	91
13 2	0.8	28	1013.7	13.1	92
13 4	1.1	38	1012.5	13.1	92
13 6	1.2	40	1012.2	13.0	93
13 8	1.1	42	1012.0	12.9	93
13 10	1.4	50	1011.0	12.9	93

Table 1: Example of rawinsonde data from Flight 1.

During the first flight the cardboard containing the rawinsonde measurements became wet after dipping into the ocean. The weight of the sensors caused the weakened cardboard to tear and the sensors to fall into the ocean (see figure 2). To assist the structural integrity of the cardboard, duct tape was wrapped around the rawinsonde for the other flights. The tape may have restricted airflow to the battery and resulted in higher temperatures being recorded.

Figure 2: Soggy rawinsonde from Flight 1.

The boom probe temperature is the preferred sea surface temperature measurement to use in the calculation of the modified refractivity index using the bulk methods. The boom probe was unserviceable during the last two flights, and the sea surface temperature measurements were taken from the engine intakes.

Analysis

During the initialisation of the rawinsonde, it is assumed the data measured was contaminated by ship affects, and therefore this initial period has been removed from each of the data files. The word ‘star’ in the file name was used to indicate the removal of the assumed contaminated data.

For each of the flights a profile of M versus height was created. Two calculations of vapour pressure were made for each two-second observation, one using air temperature, pressure and relative humidity and other using dew point temperature and pressure. These were averaged and used with air temperature, pressure and height to calculated M. Since height was only recorded to the whole metre, multiple values of M were observed at each level. These were averaged and a cubic function was fitted to the averaged values.

The original SAIL data contained information from either the previous or next day at the beginning or end of the file. This data was edited to ensure that only data for that date was contained wholly within the appropriate file. For convenience, the SAIL data was also edited to only contain data around the time of the Kite (approximately 20 minutes before and after). This should not be necessary as the main program has been written to extract only the SAIL data recorded during the time of the flight. The SAIL data was used to calculate a profile of M using bulk methods.

Annex A contains the Matlab code used to perform the required calculations and plots. The code for the functions called are not included as this code has not been modified since LT Mabey's project.

Results

The results for each flight are summarised in the following paragraphs. Table 2 provides a list of the surface observations recorded at the commencement of each flight.

Flight No	Method	No. Data Points	Surface Pressure (hPa)[1]	Surface Air Temperature (°C)	Surface Relative Humidity (%)	True Wind Speed (kts)	Sea Surface Temperature (°C)
1	Kite	2148	1016.7[2]	13.42	97.18	22.8	13.68
2	Kite	1228	1016.2	16.63	84.72	19.7	16.4
3	Balloon	3254	1016.3	13.16	99.41	2.04	13.09
4	Balloon	629	1016.3	13.93	97	12.2	13.3
5	Balloon	756	1013.9	14.0	90.6	6.0	12.72
6	Balloon	2402	1013.4	13.8	96	8.0	12.1

Table 2: Details of each flight with corresponding surface observations (from the SAIL data) at the start of each flight.

No evaporation ducts were observed using the rawinsonde data, which correlates with the foggy and overcast conditions that occurred during the cruise. The bulk data modified

[1] The observed surface pressures were taken from the rawinsonde, with the exception of flights 3 and 4 that were taken from the SAIL data.

[2] The observed surface pressure from the rawinsonde was fluctuating ±0.4hPa.

refractivity profile for Flight 2 did indicate an evaporative duct height of 5.1m, but this is not supported by the rawinsonde data or by the environmental conditions.

Flight 1

The kite was raised and lowered approximately ten times during the flight. During the last controlled descent, the rawinsonde dipped into the water with no apparent effect on the sensors. However, this event did weaken the structural integrity of the cardboard surrounding the sensors, causing the sensors to fall out and into the ocean, ending the flight.

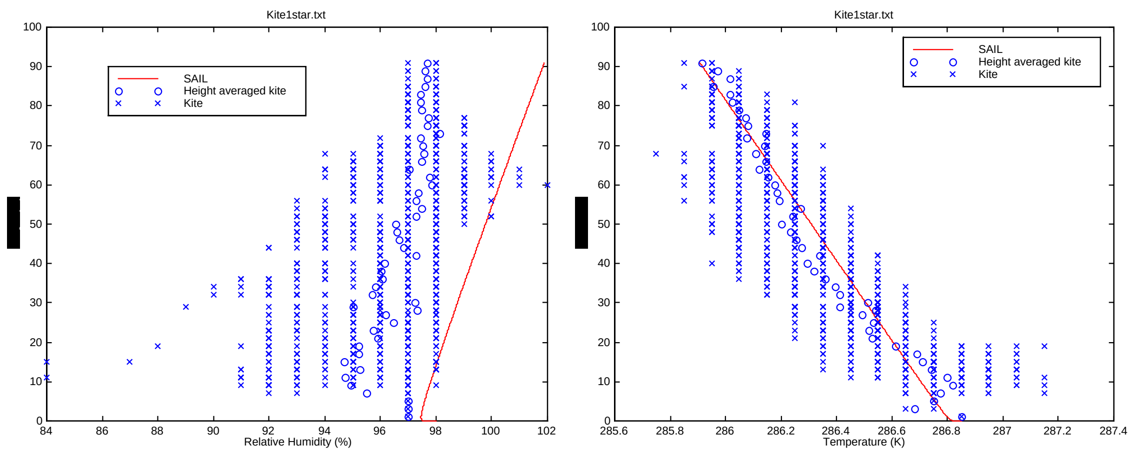

Figure 3: Relative Humidity and temperature versus height for Flight 1.

A bias exists with the relative humidity sensor of the rawinsonde with it being approximately 3% more than the SAIL surface observations. This is based on a maximum measurement of 102% when the rawinsonde was not in visible cloud. There is evidence of possible ship contamination at heights between 10 and 20m, coinciding with the ship's stack. This can be seen in the drier relative humidity and increased temperatures at those heights (see figure 3). The weather conditions of seven oktas of stratocumulus, nil precipitation and wind speeds of approximately 23kts do not support these anomalies.

Flight 2

The kite was raised and lowered approximately five times during the flight. During the second last controlled descent, the rawinsonde dipped into the water with no apparent effect on the sensors. The Kite did fall into the ocean during the last descent ending the flight.

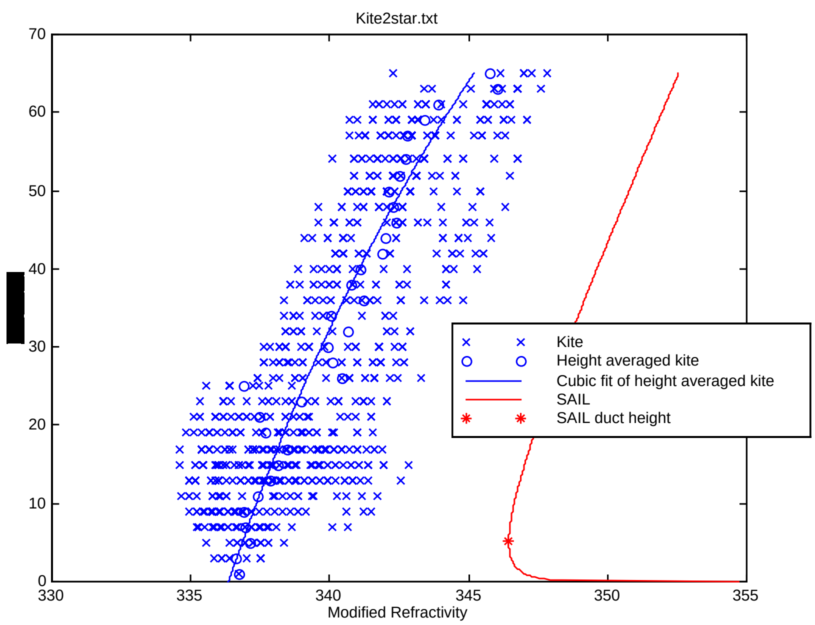

Figure 4: Modified refractivity profile for Flight 2.

A bias exists with the relative humidity sensor of the rawinsonde, with it being approximately 9% less than the SAIL surface observation. This bias could explain the significant difference in the modified refractivity profiles between the kite and the SAIL data (see figure 4). There is evidence of possible ship contamination at heights between 10 and 20m, coinciding with the ship's stack as described during Flight 1. The weather conditions of seven oktas of stratocumulus, nil precipitation and wind speeds of approximately 20kts do not support these anomalies.

Flight 3

The tethered balloon was raised and lowered approximately five times during the flight. During the second controlled descent, the rawinsonde dipped into the water with no apparent effect on the sensors. During the fourth ascent, extra string was added to the configuration in an attempt for the rawinsonde to penetrate above the fog. During the corresponding descent, the fog dissipated. In between ascents, the rawinsonde was held over the side of the ship in an attempt to measure data next to the sea surface (see figure 5).

Figure 5: How the rawinsonde was held over the side of the ship.

The flight was terminated on the Vaisala computer as the length of the flight was approaching the maximum recording time of two hours. The balloon and the sonde were still fully functional, so Flight 4 was started with the same balloon and sonde to keep recording data. During this transition period, the balloon and rawinsonde were held close to the ship’s deck. The weather during Flight 3 was initially fog with visibility less than 500m, the stratus was thin in patches to allow glimpses of the blue sky above. The wind speed was approximately 2kts. As the fog completely dissipated towards the end of the flight, the wind speed started to gradually increase to around 10kts.

A bias exists with the relative humidity sensor of the rawinsonde, with it being approximately 5% less than the SAIL surface observation. There is evidence of possible ship contamination at heights generally below 20m, coinciding not only with the ship's stack, but also with attempts to measure the lowest levels of the atmosphere by dangling the rawinsonde over the side of the ship (see figure 6). The measurements of temperature by the rawinsonde close to the surface are up to four degrees Celsius warmer than the corresponding SAIL surface temperature. The relative humidity measurements by the rawinsonde were as dry as 60% at these same heights. The weather conditions during the flight did not support these anomalies.

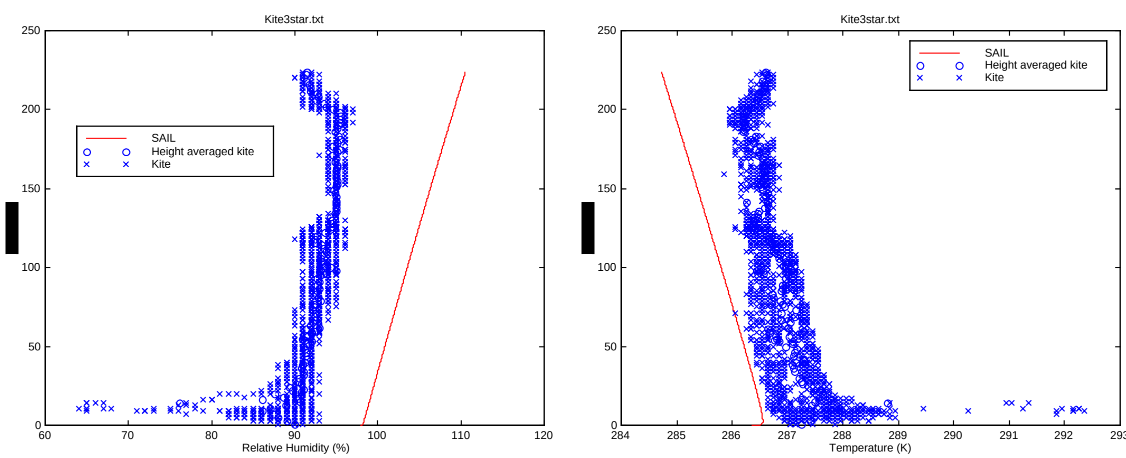

Figure 6: Relative humidity and temperature versus height for Flight 3.

Flight 4

This flight was the continuation of Flight 3. The rawinsonde data was saved as a separate flight due to the recording time limitations on the Vaisala equipment. The tethered balloon was raised and lowered twice, before being released as a 'normal' weather balloon into the atmosphere. At the end of each descent, the rawinsonde was lowered over the side of the ship in an attempt to measure the lowest levels of the atmosphere. Before the final release, the rawinsonde and the balloon were held over the deck. The weather was fine, the fog was visible in the distance, and the wind speed was approximately 12kts.

A bias continues to exist with the relative humidity sensor of the rawinsonde, with it being approximately 5% less than the SAIL surface observation. There is evidence of ship contamination at heights generally below 20m as described for Flight 3. The weather conditions during the flight did not support these anomalies.

Flight 5

The tethered balloon was raised and lowered approximately four times during the flight. During the last controlled descent the rawinsonde dipped into the water and was not able to be recovered. The weather during the flight was overcast with 8 oktas of low stratocumulus and the wind speed was approximately 6kts.

It is difficult to determine if a bias exists with the rawinsonde relative humidity sensor as can be seen in figure 7. There is evidence of possible ship contamination at heights below 40m as described in Flight 3. The weather conditions during the flight did not support these anomalies.

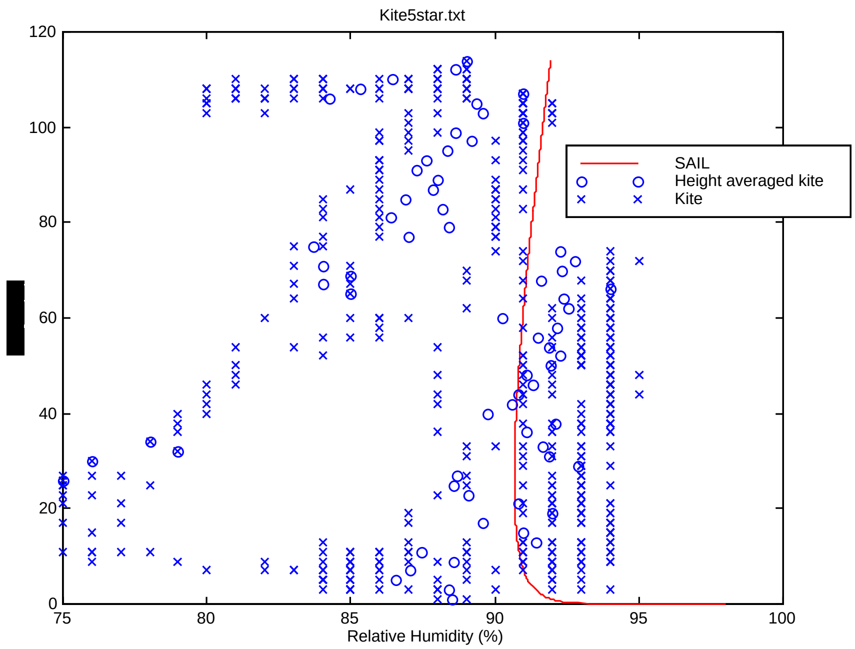

Figure 7: Relative humidity versus height for Flight 5.

Flight 6

The tethered balloon was raised and lowered approximately nine times during the flight. During the third, fifth and sixth controlled descents, the rawinsonde dipped into the ocean, with no immediate apparent effects on the sensors. The weather during the flight was fog with a wind speed of approximately 8kts.

During the fourth descent, unusually high relative humidity readings did occur, up to 106%. Although there were fluctuations in relative humidity throughout the remainder of the flight, it did not record below 100%. There is evidence of possible ship contamination at heights below 40m, as described in Flight 3. The relative humidity contamination, due to ship effects, occurred mostly during the first ascent. The weather conditions during the flight did not support these anomalies.

Summary

Although the tethered balloon was a useful alternative to the kite during periods of light winds, it is not recommended for future experiments in sampling the surface layer for evaporation duct height measurements involving R/V Point Sur. The flight data associated with the use of the tethered balloon appears more susceptible to contamination by both the stack and the proximity of the ship during the attempts to measure the lowest levels of the atmosphere.

Recommendations for Further Research

The following recommendations may reduce the contamination of the tethered balloon data in future experiments:

a. Lengthening the string between the balloon and the rawinsonde may allow the lower levels of the atmosphere to be measured whilst keeping the balloon outside of ship influences. This recommendation would also be applicable to the kite as it would not only reduce the stack influence, but it would allow the kite to remain at a higher altitude and thus have less chance of suddenly diving into the water.

b. It is possible that a different type of ship, with a different stack design, may reduce the influence on data measurements. It is acknowledged that it may not be possible to choose to use another ship.

c. Avoid dangling the rawinsonde over the side of the ship to obtain low-level measurements as the contaminated data is unable to be used in evaporation duct experiments.

The following recommendations are made for any future experiments in sampling the surface layer for evaporation duct height measurements:

a. Ensure there is enough string between the scientist and the balloon/kite to allow the rawinsonde to reach high enough into the atmosphere, especially to measure above fog banks;

b. The rawinsonde needs to be initialised as close as possible to mean sea level to prevent negative heights appearing in the data;

c. The rawinsonde needs a controlled and slow ascent and descent in order to maximise spatial resolution, and allow for any time lag in the sensors. A suitable winching system would assist in this area;

d. Good communication is required between the scientists controlling the balloon/kite and the ship's staff on the bridge to ensure that there are no sudden changes in course that cause the line to the kite to become tangled in the masts;

e. Further research is required to investigate the effects on the recorded data when taping the rawinsonde for structural support;

f. Manual observations recording when and at what height the lowest approach of the rawinsonde is, as well as any time the equipment spent on or over the deck, or endured other obvious contamination, is essential in analysing the data;

g. Ensure the SAIL instruments and rawinsonde are calibrated before use; and

h. Perfect skills in controlling a kite/balloon when trying to sample the lowest levels.

Annex

A. Matlab code used to analyse the data, printdata.m.

References:

Advanced Refractive Effects Prediction System (AREPS) Manual.

Mabey, D. L., *Evaporation Duct Profile Comparisons Using Kites and Bulk Methods*, OC3570 Project, 22 March 2001.

The photographs used on the front cover and in figures 1 and 5 are courtesy of Terry Rago (Oceanography Department, Naval Postgraduate School).

Acknowledgements

I would like to thank Professor Peter Guest (Research Associate Professor of Meteorology, Naval Postgraduate School) for his extensive support and directing my efforts throughout the project.

```
% printdata.m - To print required process SAIL and kite data
%
% LEUT Robyn Phillips
% OC3570
% September 2001
%
% Purpose:        To read in the required rawinsonde and SAIL data and calculate
%                 the modified refractivity profile for each. Plots will also be
%                 made for pressure, temperature, potential temperature, relative
%                 humidity and for specific humidity.
%
% Variables:
%                 KiteID = Flight Number identification (char array)
%                 KiteFile = Filename of the kite data to load (char array)
%                 kite = Flight data (data matrix)
%                 Time = Contains the start times UTC for each flight (data array)
%                 KNo = Numerical flight number (scalar)
%                 kitez = Kite height in metres (data array)
%                 kitep = Kite pressure in hPa (data array)
%                 kiteT = Kite temperature in Celsius (data array)
%                 kiteRH = Kite Relative Humidity % (data array)
%                 kiteTd = Kite Dew Point Temp in celsius (data array)
%                 e1 = Saturation vapour pressure (data array)
%                 e2 = Saturation vapour pressure (data array)
%                 e = Average Saturation vapour pressure (data array)
%                 a = (data array)
%                 kitem = Modified Refactivity Index for kite (data array)
%                 c = Array counter (scalar)
%                 i = Loop counter (scalar)
%                 b = Index for where the data is all of same height (data array)
%                 averagem = Avg mod Ref Index at each height for kite (data array)
%                 averageT = Avg temperature at each height for kite (data array)
%                 averageRH = Avg RH at each height for kite (data array)
%                 averagep = Avg pressure at each height for kite (data array)
%                 A = Contains polyfit of averaged M data (data array)
%                 x = (data array)
%                 y = (data array)
%                 kitezduct = Evap duct height for Kite in metres (scalar)
%                 kiteq = Specific Humidity for Kite g/g (data array)
%                 g = Gravity accelerations m/s^2 (scalar)
%                 cp = Specific heat of dry air at const pressure J/K/Kg (scalar)
%                 kitetheta = Potential temp degrees kelvin (data array)
%                 SailFile = Filename of the SAIL data to load (char array)
%                 sail = SAIL data (data matrix)
%                 StartMin = Starting minute of flight (scalar)
%                 StartHr = Starting hour UTC of flight (scalar)
```

```
%                    StartIndex = Reference index pointing to the row in the SAIL
%                                        matrix corresponding to the start time of the
kite
%                                        data (scalar)
%                    EndTime = Finishing time of the flight UTC (scalar)
%                    EndHr = Hour of the finishing time UTC (scalar)
%                    EndMin = Minute of the finishing time (scalar)
%                    EndIndex = Reference index pointing to the row in the SAIL
%                                        matrix corresponding to the end time of the
kite
%                                        data (scalar)
%                    NewSail = SAIL data that corresponds to the same times as the
%                                        flight data (data matrix)
%                    sailu = Mean wind speed from SAIL data m/s (scalar)
%                    sailT = Mean Air Temperature deg celsius from SAIL data (scalar)
%                    sailp = Mean pressure hPa from SAIL data (scalar)
%                    sailRH = Mean RH % from SAIL data (scalar)
%                    sailSST = Mean SST deg celsius from SAIL data (scalar)
%                    sailzduct = Evap duct height metres for SAIL data (data array)
%                    sailm_min = Minimum value of M profile for SAIL data (scalar)
%                    sailz = Height above surface in metres for SAIL data (data array)
%                    sailm = Modified refractivity vertical profile corresponding to
%                                 z heights for SAIL data (data array)
%                    sailP = Vertical pressure profile corresponding to z heights for
%                                 for SAIL data (data array)
%                    sailt = Vertical temperature profile corresponding to z heights
%                                 for SAIL data (data array)
%                    sailq = Vertical specific humidity profile corresponding to z
%                                 heights for SAIL data (data array)
%                    sailrhp = Vertical relative humidity profile corresponding to z
%                                 heights for SAIL data (data array)
%                    sailustar = Wind speed scaling parameter m/s for SAIL data
(scalar)
%                    sailtstar = Temp scaling parameter celsius for SAIL (scalar)
%                    sailqstar = Spec Hum scaling parameter g/g for SAIL data (scalar)
%                    saill = Monin-Obukhov Length metres for SAIL data (scalar)
%                    sailzo = Momentum roughness length metres for SAIL data
(scalar)
%                    sailzot = Thermal roughness length metres for SAIL data (scalar)
%                    m = (data array)
%                    dataprof = (data array)
%                    kiteprof = (data array)
%                    sailprof = (data array)
%                    temp = Min/max value of axis for current figure (data array)
%
% Functions used:
```

```
%                       esat2 (local function unknown author)
%                       mod_refract (local function unknown author)
%                       spec_hum (local function unknown author)
%                       evap_duct_model (local function written by Paul Frederickson)
%                       spec_hum (local function unknown author) - it is called by
%                           evap_duct_model
%                       scaling_params (local function written by Paul Frederickson) - it
%                           is called by evap_duct_model
%                       evap_duct_profile (local function written by Paul Frederickson)
%                           - it is called by evap_duct_model
%                       stability_t (local function unknown author) - it is called by
%                           evap_duct_profile
%                       stability_m (local function unknown author) - it is called by
%                           scaling_params
%
% Notes:                The data files and associated functions called must be stored
%                       either in the same directory as this file or within the path
%                       name. The file 'KiteTime.txt' is also required.
%                       One of the flights did span over the 24HR UTC and it was
%                       decided to leave the hour as 24 to ensure the plots printed
%                       correctly.
%                       The instruments of the SAIL data are assumed to be situated at
%                       a height of 17m on R/V Pt Sur
%
% This program was originally written by LT Mabey for her OC3570 in
% Winter 2001. It was then modified to suit slightly different purposes.
%
%-----------------------------------------------------------------

% Load the kite data
KiteID = input('Please enter the Kite ID number you wish to work with:  ','s');
KiteFile = ['Kite',KiteID,'.txt'];
kite = load(KiteFile);

% Load KiteTime.txt - it indicates the start time of the kite flight
Time = load('KiteTimes.txt');

KNo = str2num(KiteID(1,1));             % Flight Number

% Separate the kite data columns into different variables
kitez=kite(:,4);                        % Height
kitep=kite(:,5);                        % Pressure
kiteT=kite(:,6);                        % Temperature
kiteRH=kite(:,7);                       % Relative Humidity
kiteTd=kite(:,8);                       % Dew Point Temperature
```

```
% Calculate the saturation vapour pressure
e1=esat2(kiteT,kitep).*kiteRH/100;
e2=esat2(kiteTd,kitep);
e=(e1+e2)/2;

a=1:length(kitez);

% Calculate the modified refractivity for the kite data
% kitez-min(kitez)+1 is height above the surface
kitem=mod_refract(kiteT,kitep,e,kitez-min(kitez)+1);

% get one average value at each height to get best fit for polyfit
c=1;
for i=1:(max(kitez-min(kitez)+1))
    b=find(kitez-min(kitez)+1==i);
    if size(b,1)>0
        index(c)=i;
        averagem(c)=mean(kitem(b));
        averageT(c)=mean(kiteT(b));
        averageRH(c)=mean(kiteRH(b));
        averagep(c)=mean(kitep(b));
        c=c+1;
    end
end

A=polyfit(index,averagem,3);

% Calculate the evaporation duct height of the kite data
x=0:0.1:max(index);
y=A(4)+A(3)*x+A(2)*x.^2+A(1)*x.^3;
kitezduct=find(y==min(y))/10;

% Calculate Kite specific humidity
kiteq = spec_hum(kiteT,kiteRH,kitep);

% Calculate Kite potential temperature
g = 9.80665;
cp = 1004.67;
kitetheta = (kiteT + 273.15) + g/cp.*kitez;

% Load the SAIL data (from the ship's measurements)
SailFile = ['SailKite',KiteID(1,1),'.txt'];
sail = load(SailFile);


% Need to only retrieve the SAIL data that corresponds to when the flight
```

```
% was in progress. This is done by finding the index of the sail matrix
% that corresponds to the start time of the flight, and then find the index
% corresponding to the end of the flight. NewSail matrix then only contains
% the data between these indexes.
StartMin = Time(KNo,3) + kite(1,1);
StartHr = Time(KNo,2);

% Check to see if the minutes or hours are too big
while StartMin > 60
  StartMin = StartMin - 60;
  StartHr = StartHr + 1;
  if StartHr > 24
    StartHr = StartHr - 24;
  end
end

% Calculate the index equivalent to the start time of the kite data
StartIndex = find((sail(:,4) == StartHr) & (sail(:,5) == StartMin));

EndTime = Time(KNo,2) + Time(KNo,3)/60 + kite(length(kite),1)/60;
EndHr = floor(EndTime);
EndMin = ceil((EndTime - EndHr)*60);
EndIndex = find((sail(:,4) == EndHr) & (sail(:,5) == EndMin));

NewSail = sail(StartIndex:EndIndex,:);

% Calculate the mean values of the parameters from SAIL data
sailu=mean(NewSail(:,25));          % Mean wind speed
sailT=mean(NewSail(:,31));          % Mean Air Temperature
sailp=mean(NewSail(:,32));          % Mean Pressure
sailRH=mean(NewSail(:,34));                 % Mean Relative Humidity

% Debugging Comments
%text = sprintf('mean u = %g, meanT = %g, mean p = %g, mean RH =
%g',sailu,sailT,sailp,sailRH);
%disp(text)

% Use Boom Probe SST except for the two cruises it was U/S
if KNo == 5
  sailSST=mean(NewSail(:,36));      % Mean Ship SST
elseif KNo == 6
  sailSST=mean(NewSail(:,36));      % Mean Ship SST
else
  sailSST=mean(NewSail(:,40));      % Mean Boom Probe SST
end
```

```
% Computes the evaporation duct height, profiles and surface layer scaling
% parameters for the SAIL data
[sailzduct,sailm_min,sailz,sailm,sailP,sailt,sailq,sailrhp,sailustar,sailtstar,sailqstar,saill,sai
lzo,sailzot]=evap_duct_model(sailu,sailT,sailSST,sailRH,sailp,17,17,17,17,i);

string = sprintf('Duct height based on kite data is %g m.\nDuct height based on SAIL data
is %g m.\n',kitezduct,sailzduct);
disp(string)

m=[x' y' sailm];
dataprof=[index' averagem'];
kiteprof=[x' y'];
sailprof=[sailz sailm];

% Saving these ascii files is not working properly, come back and fix it later
save dataprof.txt dataprof -ascii
save(['dataprof',KiteID,'.txt'],dataprof) -ascii
save kiteprof.txt kiteprof -ascii
save(['kiteprof',KiteID,'.txt'],kiteprof) -ascii
save sailprof.txt sailprof -ascii
save(['sailprof',KiteID,'.txt'],sailprof) -ascii

% Plot M vs Height
plot(kitem,kitez(a)-min(kitez(a))+1,'x')
hold on
plot(averagem,index,'o')
plot(m(:,2),m(:,1),'b',m(:,3),m(:,1),'r')
plot(sailm_min,sailzduct,'r*')
legend('Kite','Height averaged kite','Cubic fit of height averaged kite','SAIL','SAIL duct
height')
xlabel('Modified Refractivity')
ylabel('Height (m)')
title(KiteFile)

% This plot is not required
%figure
%plot(sailp,sailz,'r')
%hold on
%plot(kitep(a),kitez(a)-min(kitez(a))+1,'x')
%legend('SAIL','Kite')
%xlabel('Pressure (mbar)')
%ylabel('Height (m)')
%title(KiteFile)

% Plot Temperature vs Height
figure
```

```
plot(sailt,sailz,'r')
hold on
plot(averageT+273.15,index,'o')
plot(kiteT(a)+273.15,kitez(a)-min(kitez(a))+1,'x')
legend('SAIL','Height averaged kite','Kite')
xlabel('Temperature (K)')
ylabel('Height (m)')
title(KiteFile)

% Plot Relative Humidity vs Height
figure
plot(sailrhp,sailz,'r')
hold on
plot(averageRH,index,'o')
plot(kiteRH(a),kitez(a)-min(kitez(a))+1,'x')
legend('SAIL','Height averaged kite','Kite')
xlabel('Relative Humidity (%)')
ylabel('Height (m)')
title(KiteFile)

% Plot Specific Humidity vs Height
figure
plot(kiteq,kitez,'x')
xlabel('Specific Humidity (g/g)')
ylabel('Height (m)')
title(KiteFile)
temp = axis;
axis([0.004 0.01 temp(1,3) temp(1,4)])          % Adjust the horizontal scale

% Plot Potential Temperature vs Height
figure
plot(kitetheta,kitez,'x')
xlabel('Potential Temperature (K)')
ylabel('Height (m)')
title(KiteFile)

% Plot Pressure vs Time
figure
KitePlotTime = Time(KNo,2) + Time(KNo,3)/60 + kite(:,1)/60 + kite(:,2)/3600;
plot(KitePlotTime,kitep)
hold on
SailPlotTime = NewSail(:,4) + NewSail(:,5)/60;
plot(SailPlotTime,NewSail(:,32),'--r')
legend('Kite','SAIL')
xlabel('Time (Hours)')
ylabel('Pressure (hPa)')
```

```
axis ij                                   % Reverse the vertical axis
title(KiteFile)
```